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TECHNICAL REPORT No. 75

Improvements in Tensile Testing of Composite Propellants

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Improvements in Tensile Testing of Composite Propellants

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A description is given of work which has enabled the Williams-Landel-Ferry (WLF) method of time temperature superpositioning of tensile test data to be applied to the routine assessment of experimental plastic propellant compositions. The report is in two parts. The first part deals with experimental improvements which have recently been made particularly with regard to the estimation of the effective gauge length; a comparison of the procedure with the American (ICRPG) standard method is included. The second part deals with the computerization of the calculations performed on tensile data. This has enabled the time required to carry out a WLF analysis to be reduced from one week to about one day.

Further copies of this technical report can be obtained from Technology Reports Centre, Station Square House, St Mary Cray, Orpington, Kent. BR5 3RE

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Reference: WAC/213/016

1 INTRODUCTION

The Williams-Landel-Ferry (WLF) method of time temperature superposition has been successfully applied by Vernon[1] and by Bryant, Dukes and Gledhill[2] to the determination of uniaxial tensile properties of propellants manufactured at ERDE. Recently it has been found necessary to study the low temperature, high strain rate performance of experimental batches of plastic propellant on a routine basis so that a rapid method of carrying out complete WLF reduction procedures was required.

2 EXPERIMENTAL IMPROVEMENTS

Until recently routine uniaxial tensile tests on plastic propellant were carried out on a Hounsfield machine at 25°C and at a single strain rate. With increasing interest in low temperature behaviour, the Hounsfield was adapted to operate over the temperature range +25° to -60°C and it then became possible to carry out WLF analyses by using the available crosshead speeds of 69.9, 93.8 and 279 mm/min and beams giving full scale deflections with loads of 7.26, 28.35, 56.7 and 113.4 kg. In order to improve the quality of the master curves, an Instron 1026 tensile testing machine was purchased for the routine work. This machine gives greater precision than the Hounsfield and provides a greater range of strain rates. It has cross-head speeds of 5 to 500 mm/min and, by means of a set of four load cells, the full-scale deflection of the recorder can be made to correspond to loads from 50 g to 500 kg. With this instrument, the maximum speed of response of the recorder pen is 0.5 second full scale and at low temperatures and fast cross-head speeds it was thought probable that the pen would lag behind the output of the load cells. This was confirmed by employing a Bytrex load cell coupled to a fast response Sanborn recorder. It was found that the maximum load and modulus determined from the pen records were incorrect at strain rates in excess of about 3 min^{-1}. This only affected determinations carried out under the most extreme conditions of testing, eg at -60°C and crosshead speeds of 200 and 500 mm/min. The extensibility results remained practically unaffected. Accurate temperature control of the test specimens is extremely important because the tensile properties are very temperature dependent. To achieve this the sample grips were surrounded by a box fabricated from 12 mm Tufnol and lined with 15 mm expanded polystyrene sheet. A stream of compressed air cooled by passage through liquid nitrogen was passed through the box and the temperature was controlled to within ± 0.5°C by means of an indicating controller which interrupted part of the flow of cooled air by switching a solenoid valve. The sensing element was a platinum resistance probe. The temperature of the propellant was monitored by means of a copper/constantan thermocouple inserted into the test piece.

It has been the practice at ERDE to use a dumb-bell test specimen having a parallel length of 30 mm between the shoulders with a cross-section 10 mm square. The shoulders are of 10 mm radius and the end sections 10 mm long

with a 10 × 20 mm rectangular cross-section. The American practice has been to use a so-called JANAF test piece. This is also a dumb-bell having a parallel section 51 mm long with a 9.5 × 12.7 mm cross-section. The shoulders have a radius of 12.7 mm and the end sections are 25.4 mm long with a 25.4 × 12.7 mm cross-section.

The ICRPG standard[3] now recommends the JANAF test piece only for Class B (intermediate accuracy) and Class C (rapid, but low accuracy) tests. In Class B tests the strain is measured by a plastic extensometer which should be capable of ± 1 per cent accuracy. In Class C tests a constant gauge length of 68.5 mm is assumed. Neither of these tests would be suitable for plastic propellant over the large range of test conditions required.

The ICRPG Class A (high accuracy) test is carried out on a truncated JANAF test piece stuck to tab ends. This type of specimen gives a more nearly homogeneous stress distribution than the normal JANAF test piece and an effective gauge length has been determined theoretically and experimentally confirmed. It is stated, however, that the true effective gauge length (EGL) varies from specimen to specimen (ranges up to 20 per cent observed) and as a function of strain (ranges greater than 20 per cent observed). For greater precision, therefore, the use of an extensometer with an accuracy better than 0.01 in/in is recommended for direct measurement of strain.

Before embarking on the present work a decision was made to continue using the ERDE type of test piece. However, it was also necessary to decide whether to use conventional test pieces or tab ended specimens. The use of tab ended test pieces would reduce the rate at which experimental batches could be tested. A little work was carried out on tab ended specimens and in the case of soft propellant the EGL was close to the length of parallel (30 mm) and not very dependent on strain. However, a harder propellant gave a much larger effective gauge length somewhat dependent on strain. It was concluded that the ERDE test piece corrected for variations in EGL in the manner described below would give results nearly equivalent to the Class A ICRPG test and would have the advantage of greater speed. However, for the greatest accuracy it is probable that a tab ended test piece would be preferable, provided the strain is measured directly or corrected for its variation with strain.

3 USE OF CORRECT GAUGE LENGTH FOR UNIAXIAL TESTS

The crosshead movement of a tensometer may not coincide with or be proportional to the increase in distance between two gauge marks on the test specimen and cannot, therefore, be used for a reliable determination of strain. A more accurate measurement of strain can be obtained by photographically recording the separation of the gauge marks, and if the strain induced throughout the parallel sided portion of the specimen is uniform, this is true strain. In practice there is no guarantee that the strain in the parallel sided portion is always uniform and, for the purpose of this report, the photographically measured strain will be denoted by "true strain". The EGL is defined as length which must be divided into the crosshead movement (CHM) in order to give the "true strain", ie

$$\frac{e_p}{l_p} = \frac{(CHM)}{(EGL)}$$

where e_p is the photographically determined extension on a gauge length l_p.

Deformation of the ends of the test piece and flow through the grips may raise the value of the EGL. Mechanical slackness and misalignment of the grips may also influence the EGL but in the present work any such effects were minimised by the method of interpretation of the tensometer records. Figure 1 shows three typical load/extension records obtained on the Instron machine. There is occasionally a distinct "toe" at the start of the curve, shown in exaggerated form on Figure 1, and presumably any mechanical slackness or misalignment is taken up during its formation. The linear portion of the load/extension curve is therefore extrapolated back to zero load, and the point of intersection taken as zero extension. Using this procedure there is no evidence of any change in EGL when transferring from one set of grips to another and since different grips would be expected to have different mechanical slackness, the method appears to be valid. Furthermore, when an experiment was performed on a brass test piece, there was no evidence of mechanical slackness at low strains. This confirmed that difficulties in measuring strain are a function of the test piece and not of the mechanical linkages.

It would be inconveniently time consuming to take photographic measurements in all routine testing of propellants, and therefore a quicker solution was sought. A correlation was observed between the "true strain" and the effective gauge length which enabled a correction to be made to the observed extension without recourse to routine photography. Once this relation had been determined for a given propellant, it was no longer necessary to use photography in order to establish the "true strain" of similar propellants. A description of this technique is given in the following sections.

4 EXPERIMENTAL METHOD FOR EGL DETERMINATION

Each test piece was marked with transverse lines so as to divide the parallel portion into gauge lengths ranging from 5 to 25 mm. During deformation the test piece was photographed at frequent intervals, the moment of exposure being synchronised with the depression of the Instron event marker. Tests were performed at various crosshead speeds from 5 to 500 mm/min. Experiments were performed on several widely different compositions, which included examples of plastic propellant, CTPB propellant and composite modified cast double-base propellant. The compositions are listed in Appendix A. Each photograph taken during deformation enabled a comparison to be made between photographically measured "true strain" and crosshead movement.

5 EGL RESULTS

Figures 2, 3, 4 and 5 show plots of EGL versus "true strain" for plastic propellants E3090 and E3712, CTPB propellant C37 and CMCDB propellant

E452/302/19 respectively. The results are coded according to each temperature/strain rate combination, the code being given in Figure 2. In all cases a smooth curve can be drawn through the data points. It should be emphasised, however, that the greatest difficulty in obtaining accurate measurements is in the region where the EGL is changing most rapidly, ie at low strains. The reason for this is that the machine extensions and the specimen extensions are small in this region so that errors in their determination are correspondingly high.

6 DISCUSSION OF EGL RESULTS

All the propellants examined gave similar plots of EGL versus "true strain" with the EGL almost constant at strains above 10 per cent, increasing at lower strains and becoming very large at strains below 1 or 2 per cent. The experiment with a brass test piece showed that play in the machine and mechanical linkages was not responsible for this behaviour. It is therefore evident that during the early part of any tensile test, movement of the grips produces very little strain in the parallel sided portion of the test piece. The grips used are of the roller type and if the test piece is not made entirely accurately, the area of contact would be initially rather small. It seems likely that intimate contact would be established early in the test, but during this period some deformation of the ends of the test piece may occur without a concomitant gauge length extension. It is also clear that the ends of the test pieces, above the rollers, are subjected to compressive stresses so that they will be deformed to some extent as if they were end-supported beams. Whatever the reason for the initial high EGL it is clear that the rheological properties of the material influence the value of the EGL. Thus the limiting constant value of the EGL varies from 45 to 55 mm for plastic propellant and CTPB to about 80 mm for CMCDB. Recent work with soft plastic propellants containing high proportions of binder, have shown that these materials have much lower values of EGL at small strains than either E3090 or E3712.

The effects of temperature and strain rate on the EGL of plastic propellant have recently been discussed.[4] The EGL was determined at maximum stress and rupture whereas in the present study intermediate values have also been measured. It was concluded that there is a constant EGL down to -40°C but a large increase at lower temperatures. The results also showed that the EGL increased with strain rate at the lowest temperatures. The present work suggests that the EGL depends on the strain of the test piece. At low temperatures and high strain rates the elongations at maximum stress and rupture are small, and hence they occur with a high EGL. The relationship of EGL with temperature and strain rate is therefore a consequence of the dependence of the EGL on the specimen strain.

The results of the present investigation have been taken into account in the current time/temperature reduction procedure used in the routine assessment of experimental compositions. If any measurements of strain below about 10 per cent are used, it is incorrect to assume that the EGL has an "average"

value. The method adopted is to obtain values of EGL from a plot of EGL against extension previously derived for a "standard" propellant, similar to that under test, by the method described in Sections 5 and 6. For each test, only one value of EGL, that corresponding to extension at failure, is used. This is justified because the extensions at maximum stress and at failure are identical at low temperatures and/or high strain rates where EGL varies with strain, and only differ at high temperatures and/or low strain rates where EGL is almost independent of strain.

It is considered that this method of deriving the EGL according to specimen strain gives an estimate of extension under extreme conditions, using the ERDE test piece, comparable in accuracy with the photographic method. It is however feasible that the overall EGL might not be particularly relevant. Thus any necking would invalidate this approach, as would fracture outside the gauge length. It has recently been pointed out[5] that fracture outside the gauge length often occurs with cast double-base test pieces. With plastic propellants, fracture outside the gauge length occurs only occasionally and necking is never observed under the conditions of high strain and low temperature which are of particular interest as far as motor functioning is concerned.

7 COMPUTATION OF WLF RESULTS

The most serious problem which militates against the use of the WLF reduction method for the routine assessment of propellant is that the calculations are time-consuming and tedious. A computer program was therefore devised to process the data. The program was written in Algol for use with an Elliott 903 computer and graph plotter. Raw data taken from the tensometer are handled by the program. Two versions of the program were written to suit both Hounsfield and Instron data without conversion of units.

In a typical experiment tests are performed over a range of temperature from ambient to -60°C and at crosshead speeds of 5 to 500 mm/min. Test pieces are of the usual ERDE form. The program calculates from Instron data elongation at maximum stress (LM), elongation at failure (LR), initial modulus expressed as a temperature corrected value (EC*), maximum stress corrected for extension and temperature (SM*), and the logarithm of the reduced strain rate (log RQT). The program can be terminated at this point if desired but normally a regression analysis and performance analysis are made.

8 ANALYSIS

8 1 Regression Analysis

The relationships between log LM, log LR, log EC* and log SM* each with log RQT are first subjected to a regression analysis. There is provision to fit the data either to a quadratic or cubic expression. Normally a quadratic expression is adequate. If a cubic expression is used, which is rarely necessary, the final performance analysis is omitted.

The graph plotter draws the best least square lines calculated from the mean values of the quantities obtained at each temperature/strain rate combination. Additionally all the experimental points are plotted in order to give an immediate indication of scatter. The constants of the least square equation, the semi-width confidence interval, standard deviation and correlation coefficient are calculated and printed. The limits of the axes of the plots can be varied. Four alternatives are provided and the particular one required is selected by choice of a number (1 to 4) at the beginning of the input data. The numbers are equivalent to the following conditions:

1 The data are fitted to a quadratic expression and the limits of the axes are:

log SM*, log EC*	-2 to 2
log LM, log LR	0 to 2
log RQT	0 to 7

2 The data are fitted to a quadratic expression and the limits of the axes are:

log SM*, log EC*	-2 to 2
log LM, log LR	0 to 2
log RQT	2 to 9

3 The data are fitted to a quadratic expression and the limits of the axes are:

log SM*, log EC*	-2 to 3
log LM, log LR	0 to 3
log RQT	-3 to 10

4 The data are fitted to a cubic expression and the limits of the axes are the same as 3 above for log LM and log LR. Log SM* and log EC* are not subjected to a regression analysis in this case.

The units of all these quantities are given in a later section. The most suitable limits for the axes depends on the propellant properties and the range of temperature and strain rates over which the experiment is performed.

8 2 Performance Analysis

This is not carried out if a cubic regression is used. A rocket strain rate and pressurisation extension are assumed, the actual values being 159 min^{-1} and 5.3 per cent respectively. These values are calculated for a typical high pressure rocket motor in which ability of the propellant charge to withstand pressurisation at a low temperature is a critical factor. The value of the shift factor under failure conditions is calculated from the equation relating

log LR to log RQT. This gives two solutions for log RQT, one of which is obviously irrelevant because it is outside the range of experimental conditions. From the relevant value, QT is obtained by using R = 159 min^{-1} and is then substituted in the WLF equation (see Section 9 1 4) to give the so-called predicted failure temperature (PFT). In addition the values of SM* and EC* in the failure situation are calculated and recorded. It is not considered that the failure temperature has any absolute significance; it merely enables a comparison of different propellants to be made under conditions which have some relevance to usage in a particular rocket motor.

The calculated values (from the regression equation) of SM*, EC*, LM and LR at 25°C and 279 mm/min are also printed. This enables comparison to be made with propellant test results obtained before the WLF superposition treatment was adopted. A specimen input and output referring to plastic propellant E4272 is given in Appendix B.

9 SYMBOLS, UNITS, INPUT AND OUTPUT DATA

9 1 Input Data

9 1 1 Regression Treatment and Plotter Routine

These are selected by insertion of a number 1 to 4 (see Section 8 1 above).

9 1 2 Title

The next item in the input data is the detail necessary to identify the sample.

9 1 3 Number of Experiments

The total number of experiments performed, ie the number of sets of data to be processed, is the next item in the input data.

9 1 4 Reference Temperature

The next quantity inserted is the reference temperature. The data are shifted to 20°C by use of the following equation:

$$\log QT = \frac{-900.2(T - 20)}{(121.6 - TS)(101.6 + T - TS)}$$

where log QT is the shift factor and TS the reference temperature.

If the reference temperature of a particular propellant is unknown, a useful method of determination is to optimize the superposition by using trial values of TS (TS should be about 50°C above the glass transition temperature). The program is run using various TS values and the value giving the maximum correlation coefficient is taken. The reduced strain rate is given the symbol RQT (min^{-1}).

9 1 5 Regression

The next figure in the stream of data is zero or unity. Zero stops the program before regression is carried out, while the use of unity allows the program to proceed to completion.

9 1 6 Temperature and Crosshead Speed

The temperature (^{o}C) and crosshead speed (mm/min) referring to the first set of data must be inserted to initiate the calculating procedure.

9 1 7 Experimental Data

The data referring to each test has then to be inserted in the sequence given below. All the experiments performed at a given temperature/strain rate combination must be presented consecutively. It is also most convenient from the point of view of output presentation if experiments performed at a given temperature are kept together in a group.

The sequence of data is as follows:

The temperature at which the experiment is performed (T, ^{o}C).

The crosshead speed (mm/min). This is called "nominal rate" in the output.

The load equivalent to a full scale deflection (kg).

The magnification factor (of extension) used in the experiment (M).

The extension of the test piece at maximum stress E1 (m^{-2}).

The extension of the test piece at failure E2 (m^{-2}).

The initial angle of the load/strain plot (θ degrees).

The maximum load (kg).

The EGL of the test piece (cm).

The data referring to each experiment are typed on a single line to facilitate checking. See specimen input in Appendix B.

9 2 Output Data

The crosshead speed (mm/min) and temperature (^{o}C) of each group of experiments are printed for reference. The other quantities printed for each set of data with a given strain/rate temperature combination are the reduced strain rate, the elongation at maximum stress (LM %), the elongation at failure (LR %), the UTS corrected for both temperature and elongation SM* (ie "true" and not engineering value) and the temperature corrected initial modulus EC*. SM* output is in bars, EC output is in kilobars (1 bar = 10^5 N/m^2).

A, B1, B2 and B3, the regression equation constants, are also printed. The data are fitted to equations of the type

$$y = A + (B1)x + (B2)x^2 + ((B3)x^3)$$

where the final term is usually omitted.

Following the B constants in the output data is the semi-width confidence level. Standard deviations and correlation coefficients are also given.

The other quantities which appear in the output are the PFT, SM* and EC* at failure and the values of SM*, EC*, LM and LR at 25°C and 279 mm/min. Typical outputs both data and graphical are given in Appendix B.

10 APPLICATION OF THE METHOD

To illustrate the application of the computation method, results for a sample of plastic propellant E4272 are given in Appendix B and Figures 6 and 7.

The rapidity with which a complete WLF analysis can now be carried out has enabled the method to be used as a routine procedure for the examination of experimental compositions whereas previously it was confined to candidate propellants at a comparatively late stage in their development. It has already become apparent that the previous routine procedure of testing at a single strain rate can give very misleading results with regard to behaviour at low temperatures and high strain rates, conditions which are often critical for plastic propellant. It is still considered essential to carry out motor firings for an unambiguous assessment of propellant performance under extreme conditions but the WLF master curves do provide an excellent means for the initial screening of candidate compositions. Furthermore, it is now possible to examine the effect of compositional and manufacturing variants on mechanical behaviour in a systematic and comprehensive manner. An extensive programme of work with plastic propellants based on the use of the WLF reduction procedure is in progress and the results will be reported in due course.

11 ACKNOWLEDGEMENTS

The authors have pleasure in acknowledging the invaluable assistance of Mrs W M Day in computer programming and would like to thank Mr G J Spickernell and Mr R W Bryant for helpful discussions.

12 REFERENCES

1	Vernon J H C	ERDE Technical Memorandum No 1/M/66
2	Bryant R W, Dukes W A, Gledhill R A	ERDE Technical Memorandum No 4/M/69
3		ICRPG Solid Propellant Mechanical Behaviour Manual CPIA Publication No 21 (1963) Section 4.3
4	Bryant R W, Dukes W A, Gledhill R A	ERDE Technical Note No 13
5	Willis J P, Davies R K	Summerfield Research Station Report No 70/14

COMPOSITIONS OF PROPELLANTS

E3090 (Plastic Propellant)

Ammonium Perchlorate	89%
USB2	11%

E3712 (Plastic Propellant)

Ammonium Perchlorate	74%
Aluminium	14%
Copper chromate	1%
PSB1	11%

E4272 (Plastic Propellant)

Ammonium Perchlorate	89%
PIB	8.85%
Ethyl oleate	1.15%
Twitchell surfactant	1.0%

C37 (CTPB Propellant)

Ammonium Perchlorate	79%
Aluminium	5%
Isodecyl pelargonate	2%
Thiokol HC 434) MAPO) ERL 0510)	14%

F452/302/19 (CMCDB Propellant)

Ammonium Perchlorate	25.1%
Aluminium	16.5%
NC (pyro 12.6% N)	22.3%
NG	27.2%
Triacetin	6.5%
Stabilizers	2.4%

SPECIMEN COMPUTER INPUT AND OUTPUT

Input

```
^^L4^ E4272/T1  TWITCHELL BASE RD 2428  EGL/INSTRON^
45
-35
1
25
50
```

25	50	1	4	4.55	8.4	87	0.78	4.8
25	50	1	4	4.5	8.3	87	0.68	4.8
25	50	1	4	4.6	8.6	87	0.71	4.8
25	100	2	4	4.2	8.2	84	1.08	4.8
25	100	2	4	4.85	8.6	85	0.98	4.8
25	100	2	4	4.3	8.3	85	1.12	4.8
25	500	5	4	4.7	8.45	81	2.1	4.8
25	500	5	4	4.2	8.3	82	2.1	4.8
25	500	5	4	4.3	6.9	79	1.95	5.1
-20	50	20	4	3.1	4.85	71	4.2	5.8
-20	50	10	4	3.2	5.2	81	5.1	5.8
-20	50	10	4	3.1	5.05	81	5.1	5.8
-20	100	10	4	2.8	4.2	83	6.9	6.1
-20	100	10	4	3.1	4.9	84	6.8	5.8
-20	100	10	4	3.0	5.1	83	6.15	5.7
-20	500	20	4	2.8	3.25	83	18	6.4
-20	500	50	4	2.7	3.4	75	15.5	6.4
-20	500	50	4	3.0	3.5	78	14	6.4
-40	50	50	4	2.45	3.8	82	21.5	6.2
-40	50	50	4	2.7	4.1	78	21	6.1
-40	50	50	4	2.6	4.3	78	18	6.0
-40	100	50	4	2.4	3.1	79	23.7	6.5
-40	100	50	4	2.5	3.4	80	24	6.4
-40	100	50	4	2.4	3.2	81	24.7	6.5
-40	500	100	4	1.7	2.1	82	57	7.7
-40	500	100	4	2.1	2.3	79	48.5	7.4
-40	500	100	4	2.1	2.35	79	50	7.4
-50	50	100	4	1.9	2.05	79	46	7.7
-50	50	100	4	1.95	2.2	80	38	7.5
-50	50	100	4	1.9	2.1	80	39.5	7.7
-50	100	100	4	1.3	1.5	85	62.6	8.9
-50	100	100	4	1.75	2.0	83	48	7.8
-50	100	100	4	1.5	1.7	83	49.5	8.4
-50	500	100	4	1.05	1.3	83	56	9.5
-50	500	100	4	1.4	1.4	83	72.5	9.2
-50	500	100	4	1.2	1.2	82	57	9.8
-60	50	100	4	0.7	0.7	86	82.5	13.3
-60	50	100	4	1.5	1.5	85	79.8	8.9
-60	50	100	4	1.3	1.3	84	82	9.5
-60	100	200	4	0.6	0.6	82	62.5	14-5
-60	100	200	4	0.75	0.75	83	81	12.8
-60	100	200	4	0.85	0.85	82	81	11.8
-60	500	200	4	0.5	0.5	82	33	15.0
-60	500	200	4	0.4	0.4	83	32	16.0
-60	500	200	4	0.5	0.5	82	38	15.0

Output

BGT531A

E4272/T1 TWITCHELL BASE RD2428EGL/INSTRON

NOMINAL RATE (R) = 50.00 TEMP. = 25

LOG ROT = $-1.6013_{10}-01$	LM =	$2.3698_{10}+01$
	LR =	$4.3924_{10}+01$
	SM* =	$8.7747_{10}-01$
	EC* =	$2.3574_{10}-02$

NOMINAL RATE (R) = 100.0 TEMP. = 25

LOG RQT = $1.4090_{10}-01$	LM =	$2.3177_{10}+01$
	LR =	$4.3576_{10}+01$
	SM* =	$1.2796_{10}+00$
	EC* =	$2.6665_{10}-02$

NOMINAL RATE (R) = 500.00 TEMP. = 25

LOG RQT = $7.5768_{10}-01$	LM =	$2.2478_{10}+01$
	LR =	$4.0354_{10}+01$
	SM* =	$2.4629_{10}+00$
	EC* =	$3.8908_{10}-02$

NOMINAL RATE (R) = 50.00 TEMP. = -20

LOG RQT = $1.8856_{10}+00$	LM =	$1.3506_{10}+01$
	LR =	$2.1695_{10}+01$
	SM* =	$6.2938_{10}+00$
	EC* =	$1.0806_{10}-01$

Output (contd)

NOMINAL RATE (R) = 100.00 TEMP. = -20

LOG RQT = $2.1658_{10}+00$ LM = $1.2665_{10}+01$
LR = $2.0234_{10}+01$
SM* = $8.6091_{10}+00$
EC* = $1.5289_{10}-01$

NOMINAL RATE (R) = 500.00 TEMP. = -20

LOG RQT = $2.8786_{10}+00$ LM = $1.1068_{10}+01$
LR = $1.3216_{10}+01$
SM* = $2.0308_{10}+01$
EC* = $3.7818_{10}-01$

NOMINAL RATE (R) = 50.00 TEMP. = -40

LOG RQT = $3.4565_{10}+00$ LM = $1.0593_{10}+01$
LR = $1.6681_{10}+01$
SM* = $2.7969_{10}+01$
EC* = $5.5438_{10}+01$

NOMINAL RATE (R) = 100.00 TEMP. = -40

LOG RQT = $3.6839_{10}+00$ LM = $9.4091_{10}+00$
LR = $1.2504_{10}+01$
SM* = $3.3117_{10}+01$
EC* = $6.0778_{10}-01$

NOMINAL RATE (R) = 500.00 TEMP. = -40

LOG RQT = $4.3829_{10}+00$ LM = $6.5696_{10}+00$
LR = $7.5092_{10}+00$
SM* = $6.9248_{10}+01$
EC* = $1.4367_{10}+00$

Output (contd)

NOMINAL RATE (R) = 50.00 TEMP. = -50

LOG RQT = $4.3961_{10}+00$

LM = $6.2792_{10}+00$
LR = $6.9358_{10}+00$
SM* = $5.7331_{10}+01$
EC* = $1.4425_{10}+00$

NOMINAL RATE (R) = 100.00 TEMP. = -50

LOG RQT = $4.6688_{10}+00$

LM = $4.5750_{10}+00$
LR = $5.2278_{10}+00$
SM* = $7.3076_{10}+01$
EC* = $2.6791_{10}+00$

NOMINAL RATE (R) = 500.00 TEMP. = -50

LOG RQT = $5.2216_{10}+00$

LM = $3.2096_{10}+00$
LR = $3.4289_{10}+00$
SM* = $8.3675_{10}+01$
EC* = $2.5456_{10}+00$

NOMINAL RATE (R) = 50.00 TEMP. = -60

LOG RQT = $5.5412_{10}+00$

LM = $2.9834_{10}+00$
LR = $2.9834_{10}+00$
SM* = $1.1504_{10}+02$
EC* = $4.5891_{10}+00$

NOMINAL RATE (R) = 100.00 TEMP. = -60

LOG RQT = $5.8275_{10}+00$

LM = $1.4334_{10}+00$
LR = $1.4334_{10}+00$
SM* = $1.0418_{10}+02$
EC* = $6.9953_{10}+00$

Output (contd)

NOMINAL RATE (R) = 500.00 TEMP. = -60

LOG RQT = $6.5264_{10}+00$

LM = $7.6389_{10}-01$
LR = $7.6389_{10}-01$
SM* = $4.8851_{10}+01$
EC* = $8.2530_{10}+00$

ANALYSIS

SM*	A	=	$-3.5198_{10}-02$				
	B1	=	$5.8962_{10}-01$	$2.9623_{10}-02$	S. DEV	=	$1.1721_{10}-01$
	B2	=	$-4.3491_{10}-02$	$4.5612_{10}-03$	C.C.	=	$9.8617_{10}-01$
EC*	A	=	$-1.6467_{10}+00$				
	B1	=	$3.9132_{10}-01$	$2.7415_{10}-02$	S. DEV	=	$1.0847_{10}-01$
	B2	=	$2.2213_{10}-03$	$4.2212_{10}-03$	C.C.	=	$9.9210_{10}-01$
LM	A	=	$1.3341_{10}+00$				
	B1	=	$2.0855_{10}-02$	$2.8489_{10}-02$	S. DEV	=	$1.1272_{10}-01$
	B2	=	$-3.4961_{10}-02$	$4.3865_{10}-03$	C.C.	=	$9.6855_{10}-01$
LR	A	=	$1.6119_{10}+00$				
	B1	=	$-2.2431_{10}-02$	$2.9404_{10}-02$	S. DEV	=	$1.1634_{10}-01$
	B2	=	$-3.5455_{10}-02$	$4.5274_{10}-03$	C.C	=	$9.7702_{10}-01$

PFT = $-2.7407_{10}+01$

FRACTURE SM* = $5.9533_{10}+01$
FRACTURE EC* = $1.7393_{10}+00$

AMBIENT SM* = $3.2413_{10}-01$ AMBIENT EC* = $1.1646_{10}-02$
AMBIENT LM = $2.0052_{10}+01$ AMBIENT LR = $4.0895_{10}+01$

S No 21/71/GC

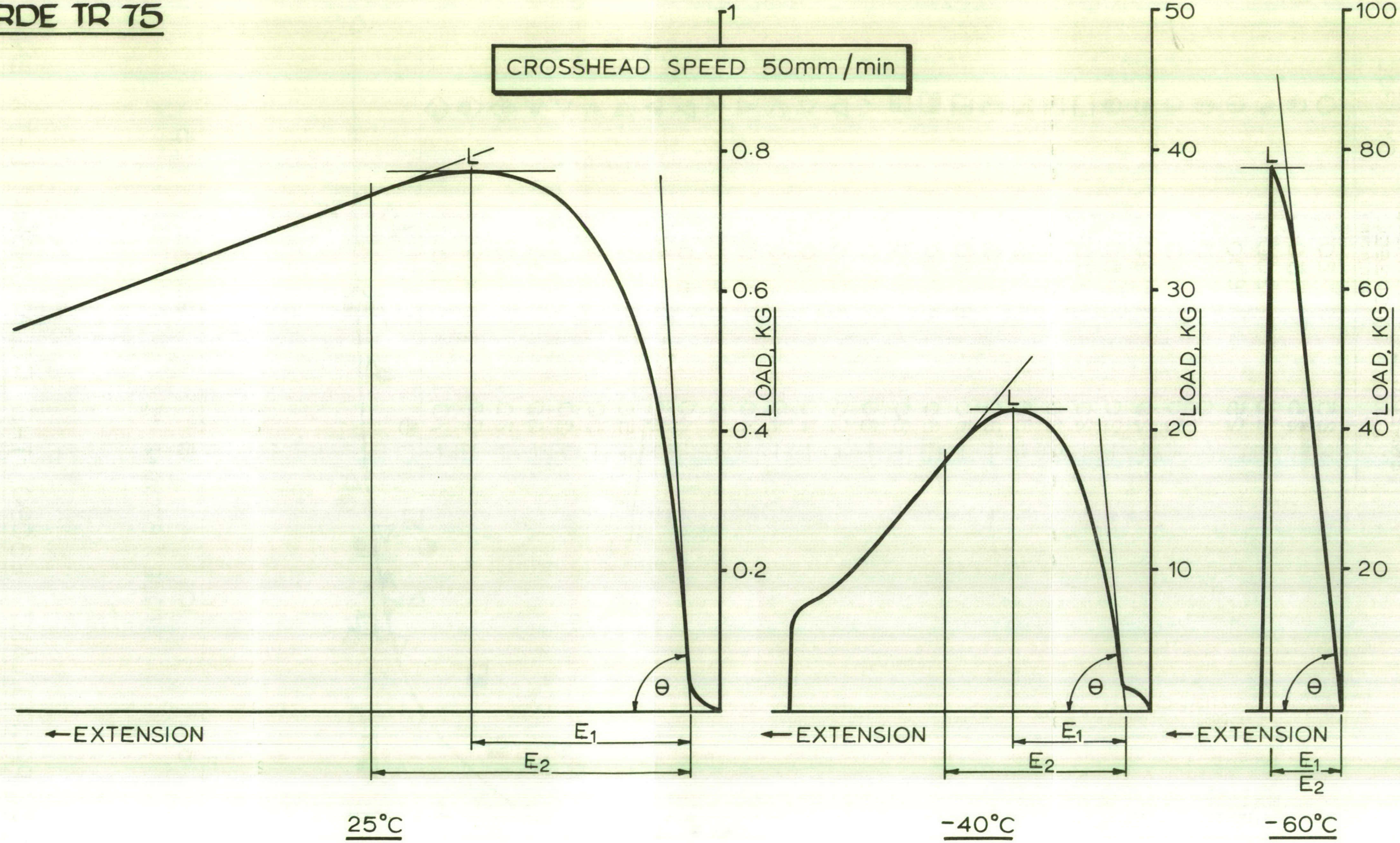

FIG. 1. TYPICAL LOAD / EXTENSION CURVES FOR PLASTIC PROPELLANT E4272/T1

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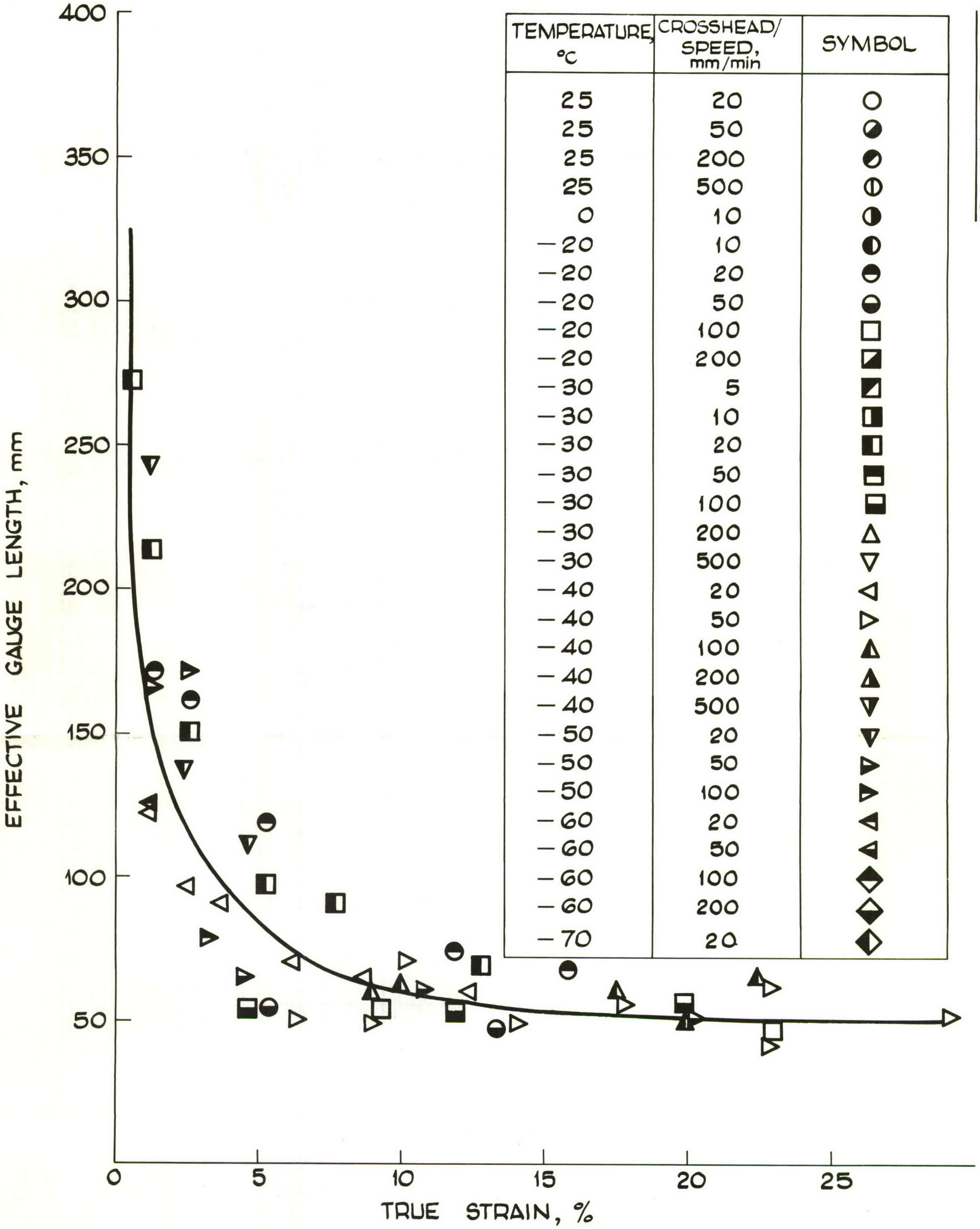

FIG. 2 PLASTIC PROPELLANT E3090. THE RELATIONSHIP BETWEEN EFFECTIVE GAUGE LENGTH AND TRUE (PHOTOGRAPHIC) STRAIN.

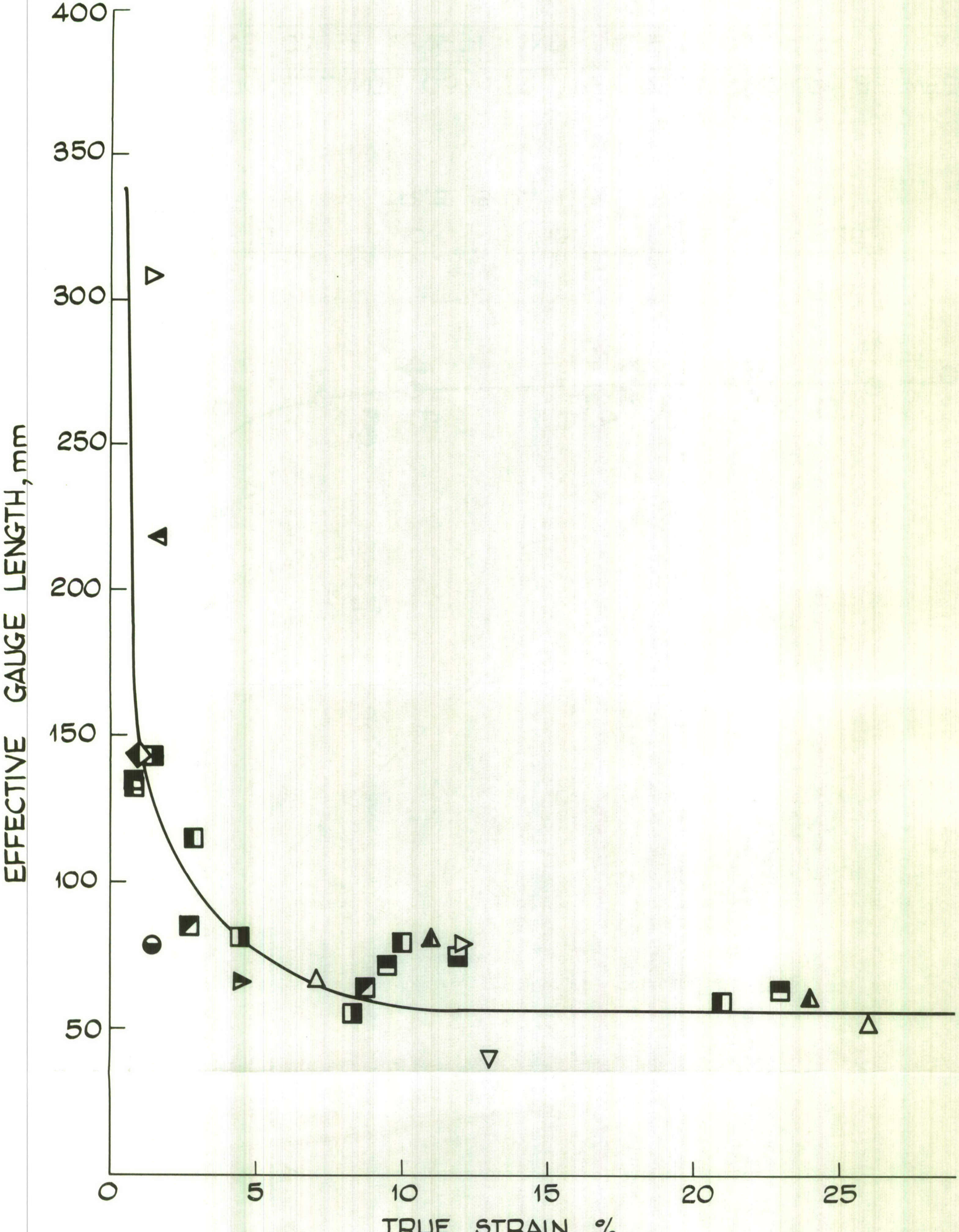

FIG.3 PLASTIC PROPELLANT E3712. THE RELATIONSHIP BETWEEN EFFECTIVE GAUGE LENGTH AND TRUE (PHOTOGRAPHIC) STRAIN.

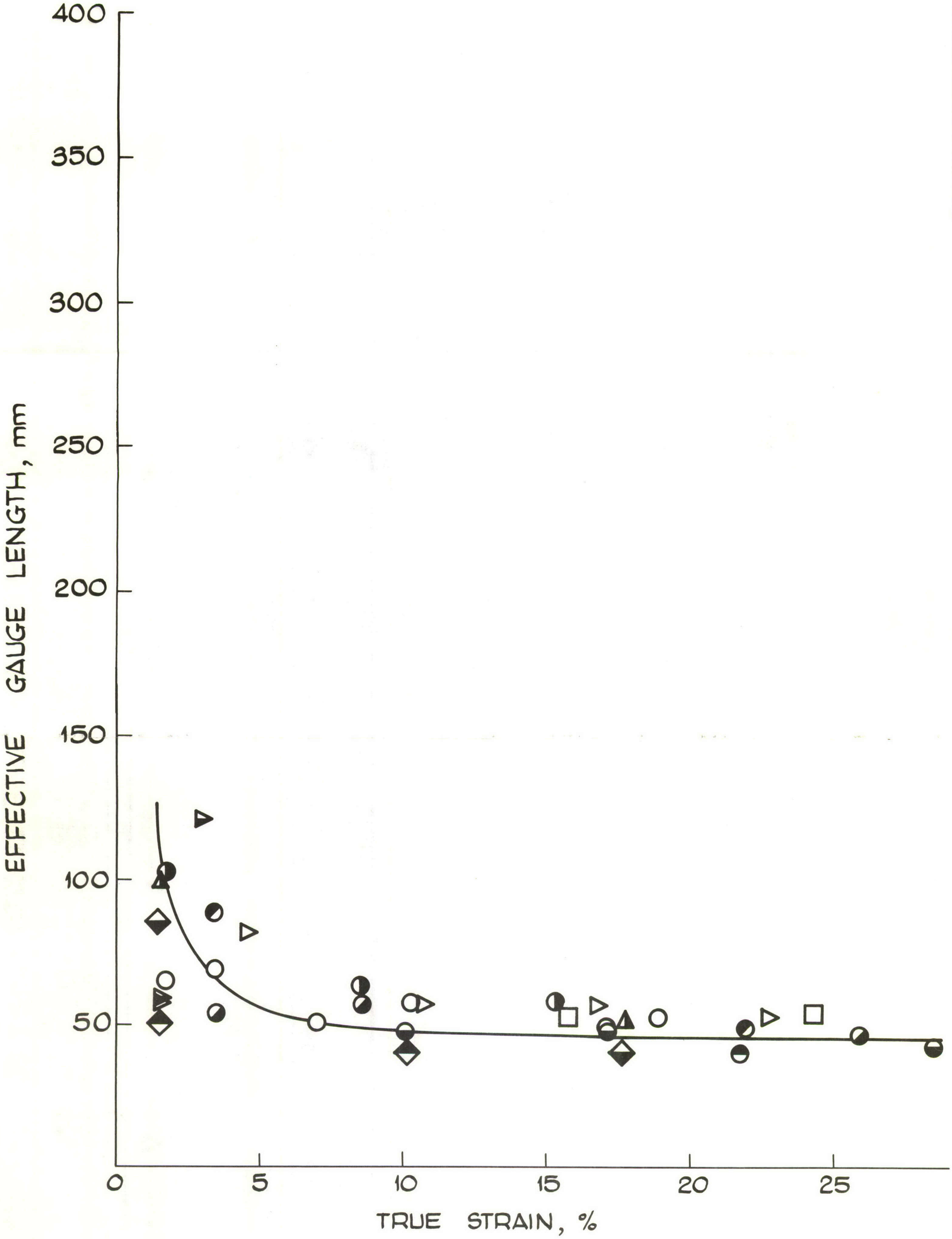

FIG. 4 CTPB PROPELLANT C37/157. THE RELATIONSHIP BETWEEN EFFECTIVE GAUGE LENGTH AND TRUE (PHOTOGRAPHIC) STRAIN.

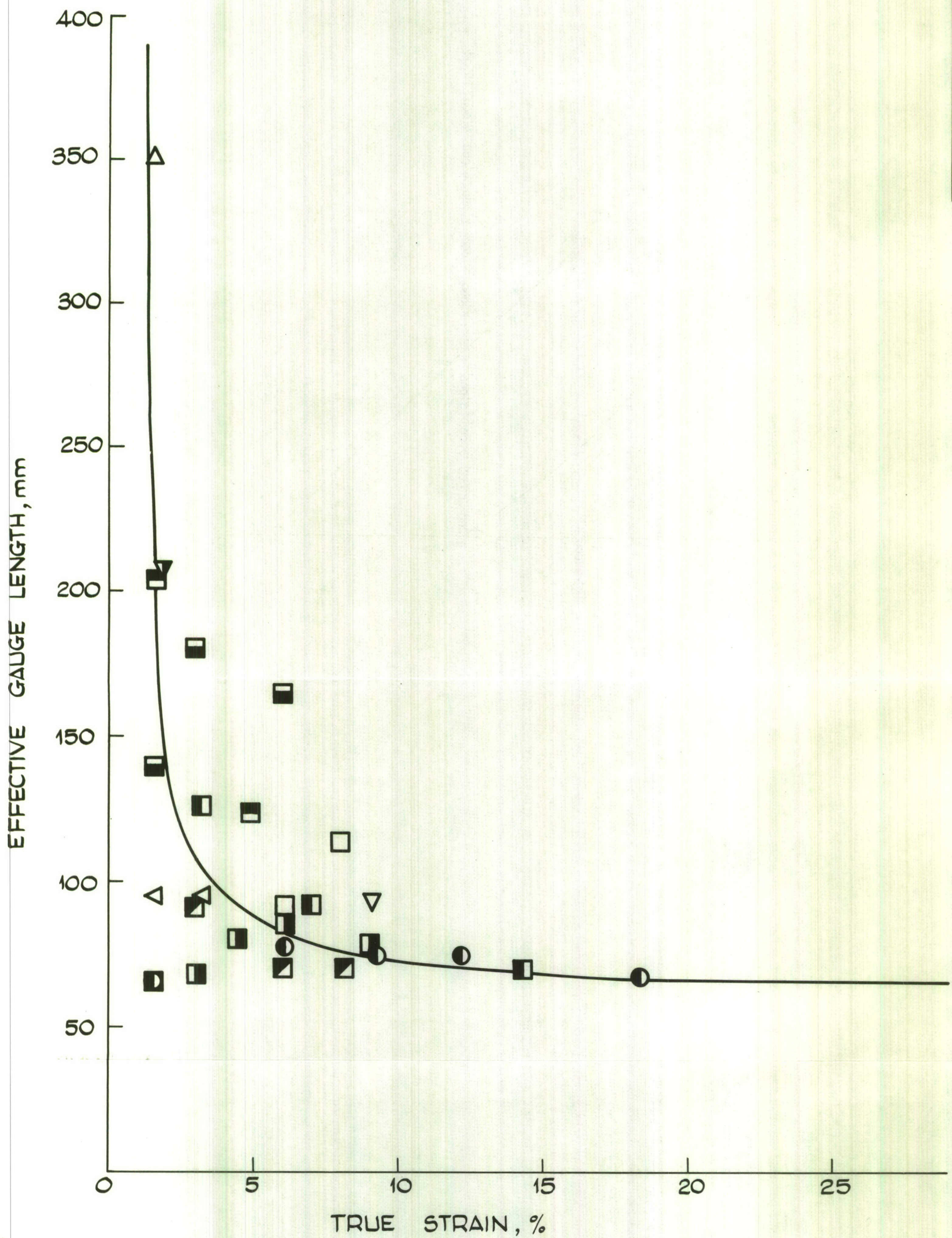

FIG. 5 CMCDB PROPELLANT. THE RELATIONSHIP BETWEEN EFFECTIVE GAUGE LENGTH AND TRUE (PHOTOGRAPHIC) STRAIN.

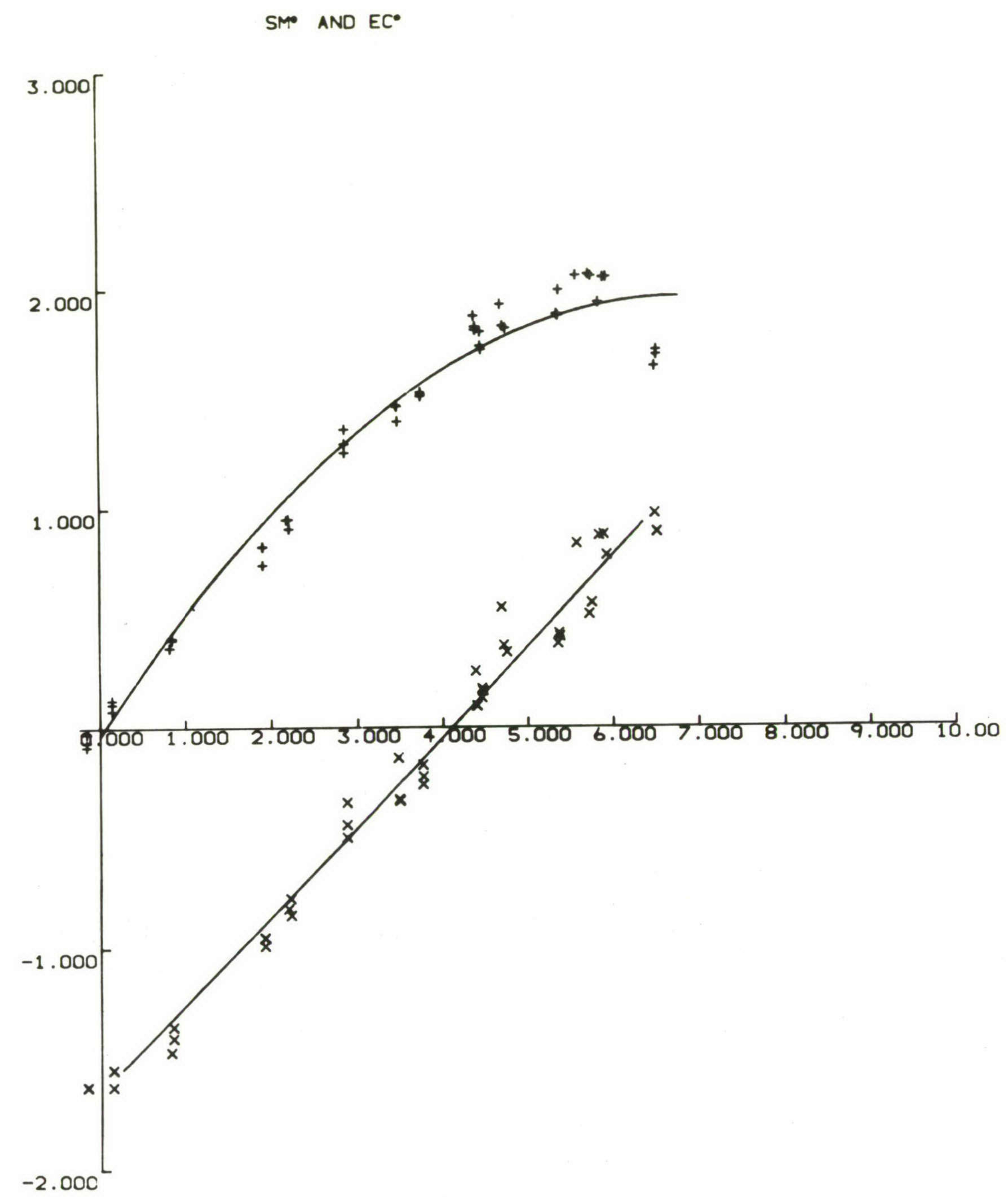

FIG.6 E4272 GRAPHICAL COMPUTER OUTPUT $SM^x(+)$ AND $EC^*(x)$

ERDE TR 75

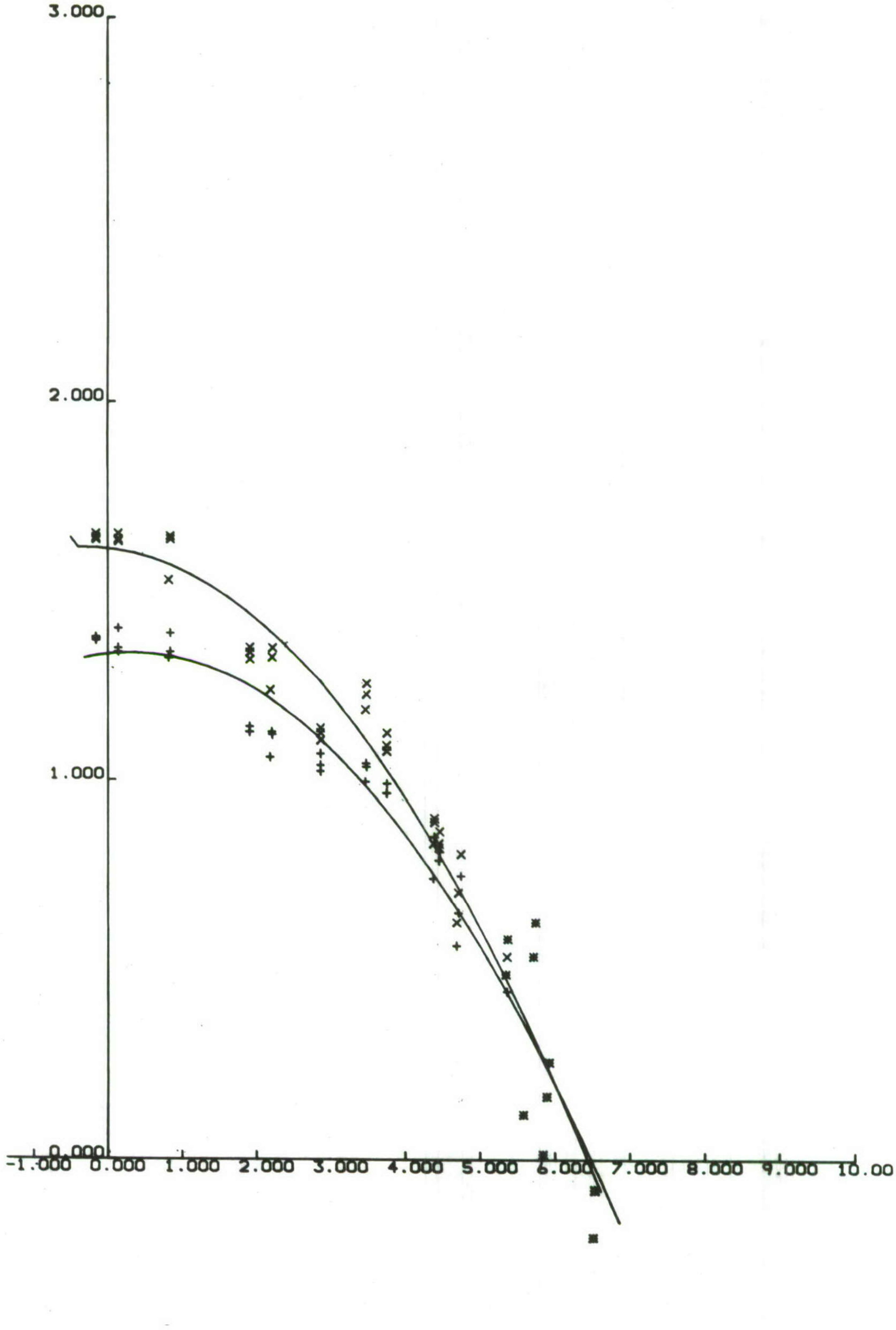

FIG.7 E4272 GRAPHICAL COMPUTER OUTPUT LM(+) AND LR(x)

Technical Report No 75
Explosives Research and Development Establishment
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Ayerst R P, Tucker B G
July 1971
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